

High-endurable memristors based on ReSe₂/BST:YSZ ferroelectric heterojunctions for optical encryption communication

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ABSTRACT: Due to the increasing awareness of space security, encrypted space optic-communication has attracted significant attention. Consequently, ferroelectric memristors with efficient data processing capability and high operational stability become essential. However, inorganic perovskite materials such as Ba_{0.6}Sr_{0.4}TiO₃ (BST) typically respond only to near-ultraviolet light, exhibiting relatively weak photo-response currents. In this work, we introduce a two-dimensional ReSe₂/BST:YSZ (BST doped with (ZrO₂)_{0.92}(Y₂O₃)_{0.08}) hetero-memristor that demonstrates robust photoelectric capability. The heterostructure achieves visible-light perception through the ferroelectric modulation of ReSe₂ by BST:YSZ, resulting in an optical current switching of up to 50 μ A. The device exhibits excellent endurance, maintaining stable optical switching over 30,000 cycles, and enables the simulation implementation of optical logic gates (AND, OR, XNOR, XOR and ODD checker) suitable for airborne information encryption and transmission. Moreover, the hetero-memristor emulates synapse-like regulation behaviors, including transitions between synaptic facilitation and depression under paired-pulse stimulation, and plasticity evolution from long-term potentiation to long-term depression under continuous stimulation. Based on these properties, an optical encryption communication system is demonstrated, achieving a recognition accuracy of up to 99.8%. This work provides a new approach toward integrating photovoltaic and ferroelectric functionalities for secure space communication applications.

KEYWORDS: hetero-memristor, ferroelectric, layered ReSe₂, Ba_{0.6}Sr_{0.4}TiO₃ (BST):YSZ, optical communication

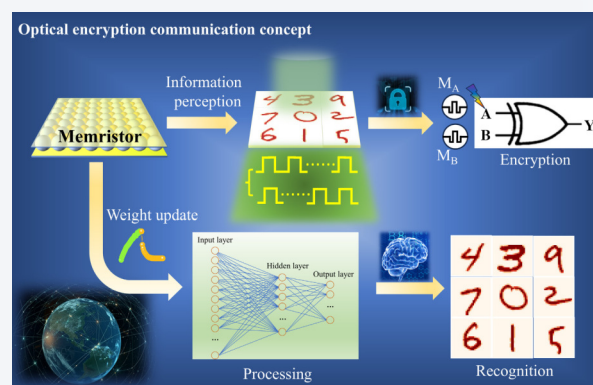
1 Introduction

Nowadays, optical information transmission exhibits the strong penetration and high environmental adaptability [1, 2], driving to the emergence of optical communication systems [3, 4]. However, in an era of such frequent information exchange, communication security [5] has become an urgent issue that needs to be addressed. Meanwhile, in optical communication networks, the strong perception ability and excellent storage capacity are required.

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Therefore, the ferroelectric hetero-memristor has received extensive attention for its spontaneous polarization [6–8] and tunable polarization characteristics [9, 10]. In recent years, pure inorganic ferroelectric materials (such as Pb[Zr_xTi_{1-x}]O₃ [11–13], BaTiO₃ [14, 15], LiNiO₂ [16], Ba_{1-x}Sr_xTiO₃ [17], and BST:YSZ [18]) have been studied and applied to ferroelectric memristors. However, most of them can only respond to the limited optical bandwidth of light and often encounter problems such as breakdown and unstable hysteresis behavior which has limited its application in optical broadband communication [19].

Since 2004, Novoselov [20] and Mueller [21] et al. have successfully stripped graphene nanosheets and applied them in field effect transistors for ultrafast light detection, demonstrating the potential of two-dimensional materials for building highly integrated and efficient photodetectors. Due to the unique layered structure, two-dimensional (2D) materials can generate photons

under light stimulation, and ferroelectric materials can be used as excellent light absorption layers [22]. Therefore, some study introduced the 2D materials to ferroelectric materials to construct hetero-memristors which can realize the regulation of optical and ferroelectric behavior through the polarization modulation [23]. Chen et al. achieved wide spectrum multifunctional optical information detection under ferroelectric modulation by integrating GeSe/MoS₂ van der Waals heterojunction and poly based ferroelectric-tuned van der Waals heterojunction [9]. Shrivastava et al. introduced ZnO:Al on the BST layer to achieve bidirectional photoelectric response at 405 and 633 nm wavelengths [24]. Yang et al. also achieved switching between n-n type and Schottky type junctions by controlling the contact type of VO₂/Nb:TiO₂ heterojunction devices through temperature regulation of VO₂ thin films [25]. According to those studies, the regulation of the barriers about the hetero-memristor can modulate the charge carriers, optimize the optical performance, thus providing a new idea for optical communication sensing in free space. However, there has been relatively little research on improving optical perception range and the further application about it.

Here, ReSe₂ was spin-coated on BST:YSZ films to fabricate the ReSe₂/BST:YSZ hetero-memristor, because of the excellent carrier mobility [26] of ReSe₂ and the ferroelectric properties [27] of BST:YSZ. Based on this, the hetero-memristor achieves high-voltage endurable ferroelectric polarization characteristic. Furthermore, it realized the biologic-synapse-like simulation: including a transition from paired-pulse facilitation (PPF) to paired-pulse depression (PPD), and the simulation of long-term potentiation (LTP) → long-term depression (LTD). For the most important, by adjusting the potential barrier between ReSe₂/BST:YSZ through ferroelectric polarization of BST:YSZ, the device realizes the large optical response under visible light. Optical logic operations (AND, OR, XOR, XNOR, and ODD checker) are simulated by converting the photocurrent into photovoltage. Based on those, we finally constructed the optical encryption communication system which could use for low-dimensional information encryption. Based on LTP/LTD characteristics, a neural network with a high recognition rate can be achieved, providing a new approach for photovoltaic integration systems in secure communication.

2 Results

In optical communication systems (as shown in Fig. 1), there exists a highly complex and interconnected communication network. Memristors can sense optical imaging, or perform complex brain-like neuromorphic computing through complex conductance changes or variable mapping. Regarding the optical sensing part, when the device is stimulated by light, it will obtain a series of optical pulses composed of photocurrents, thereby obtaining a series of optical codes that we desire. By performing XOR or XNOR logical operations between these optical codes, low-dimensional encrypted codes can be obtained, which is corresponding to our work. Meanwhile, in the neuromorphic computing, it can realize the updating of synaptic weights within a neural network layer based on the LTP/LTD linear conductance of memristors, facilitating the acquisition of accurate images. To better achieve low-dimensional logical encryption and brain-like recognition, we have fabricated the ReSe₂/BST:YSZ hetero-memristor with photoreceptive and brain-like behavior simulation capabilities, as illustrated in Fig. 2(a), represents a multifunctional device capable of integrating both sensing and processing within a single platform. In this structure diagram, P-Si and SrTiO₃ (STO) were prepared as the substrate, La_{0.67}Sr_{0.33}MnO₃ (LSMO) is used as the bottom electrode and Pd is the top electrode. The subsequent section presents a more detailed discussion of its structural characteristics and operational mechanisms. The ReSe₂ consists of a Re atom plane sandwiched between two Se atom planes, as shown by the inset of Fig. 2(a), with narrow bandgap and strong carrier mobility, laying the foundation for its unique optical properties [28]. To further explore the detail about the van der Waals ReSe₂, the TEM image was shown in Fig. S1 in the Electronic Supplementary Material (ESM). It shows a polygonal particle, with relatively clear edges, indicating that the crystal has distinct crystal faces, and morphology is regular. The X-ray photoelectron spectroscopy of ReSe₂ shown in Fig. S2 in the ESM shows the nuclear spectrum of Re 4f and Se 3d, respectively, which could reflect the basic elemental composition and the structural integrity. These peaks are consistent with previously reported data [28]. To confirm the crystalline phase and structural stability of ReSe₂/BST:YSZ, the X-ray diffraction

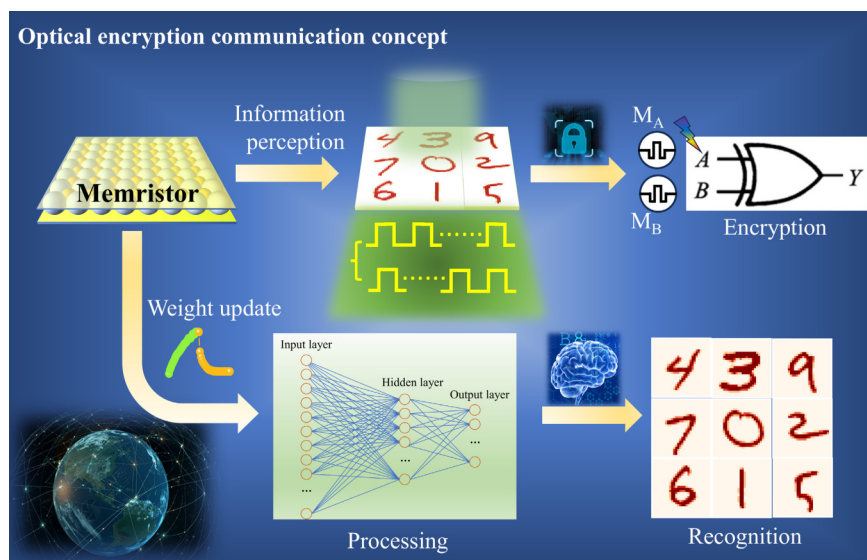


Figure 1 Schematic diagram illustrating the functional use of hetero-memristors in optical perception and neuromorphic computation recognition in optical encrypted communication systems.

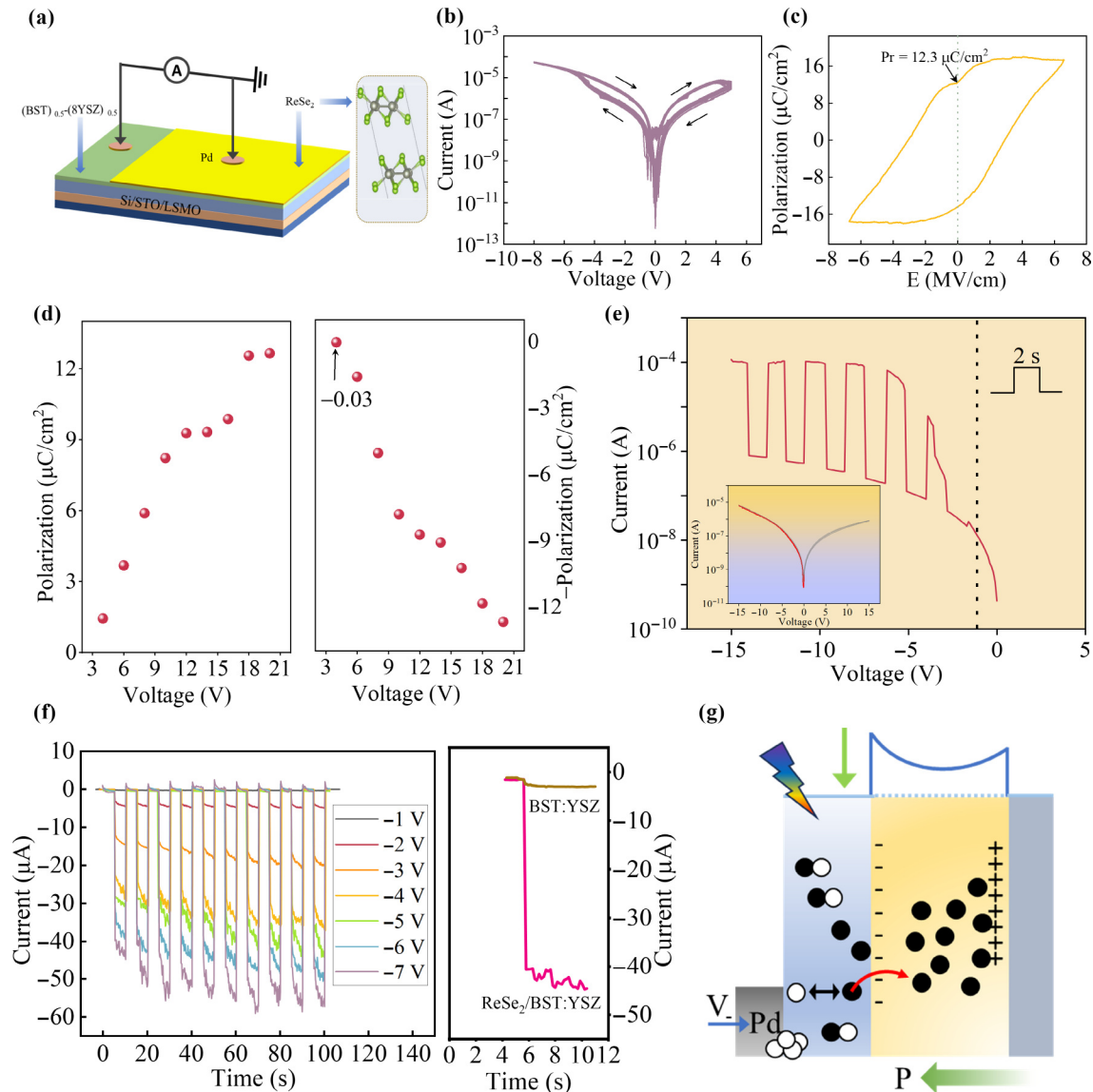


Figure 2 Basic materials features and ferroelectric properties of $\text{ReSe}_2/\text{BST:YSZ}$ hetero-memristor. (a) The structure diagram of $\text{Pd}/\text{ReSe}_2/\text{BST:YSZ}/\text{LSMO}/\text{STO}/\text{Si}$. (b) $0\text{ V} \rightarrow 6\text{ V} \rightarrow 0\text{ V} \rightarrow -8\text{ V} \rightarrow 0\text{ V}$ scanning I - V curves (logarithmic form). (c) P - E loop ($\text{Pr} = 12.3\text{ }\mu\text{C}/\text{cm}^2$). (d) Variation of polarization value under the 4 - 20 V . (e) Partial I - V scanning under 405 nm optical pulse stimulation (pulse width: 2 s). (f) Variation of optical current by voltage regulation from -1 to -7 V and the comparison of photoresponse currents between BST:YSZ and $\text{ReSe}_2/\text{BST:YSZ}$. (g) The variation of the interface barrier when the negative voltage applied.

spectrum was shown in Fig. S3 in the ESM. The diffraction peaks of STO (001) [(001) and (002)] and LSMO (001) are shown [29]. It also shows the ReSe_2 (001) diffraction peak at $2\theta = 13^\circ$ [30].

After confirming the structural stability, the memristive characteristics of the hetero-memristor were further investigated. The I - V curves over 100 cycles were measured under a voltage sweep of $0\text{ V} \rightarrow 6\text{ V} \rightarrow 0\text{ V} \rightarrow -8\text{ V} \rightarrow 0\text{ V}$, as shown in Fig. 2(b). It exhibits unique memristor switching characteristics and highly cycle consistency. As the $0\text{ V} \rightarrow -8\text{ V}$ was scanned, the device transitioned from the high-resistance state to the low-resistance state and the device turned to the set state. When the $0\text{ V} \rightarrow 6\text{ V}$ applied, the device switched back from LRS to HRS, in the reset state. And the memristor exhibits superior retention characteristics, the 10^4 s retention under LRS and HRS is shown in Fig. S4 in the ESM. We further analyze the ferroelectric properties of $\text{ReSe}_2/\text{BST:YSZ}$ hetero-memristor, which expected to modulate the Schottky barrier between BST:YSZ and ReSe_2 through ferroelectric

polarization, thereby affecting its optical properties. The P - E loop under 20 V in Fig. 2(c) represents the ferroelectric property of the device, which demonstrate the $\text{Pr} = 12.3\text{ }\mu\text{C}/\text{cm}^2$. According to this, the polarization values of different voltages under 4 - 20 V are summarized in Fig. 2(d). With the increase of voltage, the Pr values become larger, which does not reach the saturation polarization state at 20 V . It should also be clarified that the 4 V corresponds to “-Polarization” is negative.

Figure S5(a) in the ESM shows the ferroelectric polarization flip fatigue characteristics of the device at 10^7 laps, and when the number of flip-turn reaches 10^5 laps, the polarization value shows the significant attenuation. And the degradation in endurance may affect the synaptic stability of the device [31]. The specific P - E loop curves are shown in Fig. S5(b) in the ESM.

To further investigate the specific effects of light application on the memristor characteristics of the device and the factors influencing the changes in its photoresponse, continuous light

pulses with a pulse width of 2 s were applied to the device during continuous I - V testing from 0 V $\rightarrow$ -15 V. As shown in Fig. 2(e), initially, the BST:YSZ film was in an unpolarized state, and no photoresponse was observed. As the voltage increased, the thin film polarization led to a decrease in the barrier, and photoresponse behavior gradually appeared. With the gradual increase of voltage, the degree of barrier modulation increased, and the degree of photoresponse gradually increased. Then -1-7 V was applied to explore the principle of the optical response behavior as shown in Fig. 2(f). Due to the unique optical properties of ReSe_2 [27], when it is combined with the BST:YSZ composite material, enhanced optical perception can be achieved by regulating the interfacial potential barrier. In Fig. S6 in the ESM, we applied the light on an electrode with an area of $1.96 \times 10^{-5} \text{ cm}^2$, the light irradiation range is a circle with a diameter of 2 mm. The current response of BST:YSZ without ReSe_2 reaches only up to 10 μA . However, the introducing of ReSe_2 could improve it to almost 50 μA and the wider band response. The corresponding comparison of photocurrent response before and after the introduction of ReSe_2 is shown in right of the Fig. 2(f). It was found that as the negative voltage increased, the variation of the response current increased, indicating that the optical response is caused by the ferroelectric polarization regulating the interface potential barrier [32]. The dark is almost 10^9 A , as shown in Fig. S7 in the ESM.

BST:YSZ is a wide-bandgap ferroelectric oxide [33], and its optical response is mainly dominated by intrinsic band-to-band transitions. Under visible light irradiation, because the photon energy is insufficient to overcome the bandgap, BST:YSZ is difficult to generate effective photoexcited carriers and only exhibits a very weak or even unmeasurable photoelectric response. ReSe_2 , which has strong light absorption in the visible spectrum and a relatively high efficiency of photogenerated carrier generation is a narrow-bandgap layered semiconductor with a bandgap of approximately 1.2 eV. Due to the differences in work function and electron affinity between ReSe_2 and BST:YSZ, when they come into contact, band bending occurs at the interface, forming an interfacial barrier and generating a built-in electric field as shown in Fig. S8(a) in the ESM. This built-in electric field plays a key role under illumination, providing the physical driving force for the directional separation of photogenerated carriers and their transfer across the interface. Due to the large bandgap difference between BST:YSZ and ReSe_2 , when the heterostructure is newly formed, some photo-generated holes find it difficult to be transported, resulting in almost no change in the photo-generated current. When the main absorption layer shifts from BST:YSZ to ReSe_2 , visible light is first absorbed in ReSe_2 , generating photogenerated electron-hole pairs. With ferroelectric polarization occurring as shown in Fig. 2(c), the barrier between BST:YSZ and ReSe_2 is modulated, allowing more photogenerated electrons to be transported and resulting in a larger photocurrent. Obviously, the two conditions of no light and under light, the linearity of $\ln(I)$ and $|V|^{1/2}$ is approximately 0.992 and 0.988, as shown in Fig. S8(d) in the ESM, indicating that the conduction mechanism of optical during the setting process is mainly provided for Schottky emission behavior.

A more specific explanation of the mechanism is in Fig. S8 in the ESM.

This heterostructure memristor will also possess unique synapse-like simulation capabilities due to its unique ferroelectric properties. Biological synapses are the most important behavioral pattern for information transmission in our body [34]. As shown in the left

part of Fig. 3(a), when the biological spikes are applied to the presynaptic membrane, it will secrete neurotransmitters into the synaptic cleft and be received by the postsynaptic membrane, generating the biological postsynaptic current. This device can mimic the similar synaptic information transmission behavior. When the electrical spike pulse applied to them, it can generate the corresponding current as shown in the right part of Fig. 3(a). And depending on the degree of stimulation, the conductance also varies, which effectively realizes conductance regulation. In Fig. 3(b), the variations of excitatory postsynaptic current (EPSC) after applying different amplitudes pulses (-4, -5, -6, -7, and -8 V) are shown. It is obvious that as the amplitude increases, the response current gradually increases, with the generated EPSC increasing gradually. Based on this, four different amplitudes of -2, -4, -6, and -8 V were applied to the device for 30 consecutive pulses, and the conductance variations are shown in Fig. 3(c). The illustration shows the comparison of the last pulse conductance under different voltages. With the amplitude increased, the conductance becomes larger dramatically, which could prove that different stimulation level can achieve different conductance changing.

In Fig. 3(d), the influence of pulse width on the device conductance value was studied, and the illustration shows the comparison of the last pulse conductance under different duration times. And the changes of the EPSC after applying five different width pulses of 1, 5, 10, 20, and 50 μs , respectively were shown in Fig. 3(e). As the pulse width increases, the changing rate of EPSC decreases. Keeping the pulse interval unchanged, as the pulse width increased (1, 3, 5, 10 μs), the conductance became larger with the increasing trend more obvious. Similarly, by changing the pulse interval (1, 3, 5, 10 μs), as shown in Fig. 3(f), the conductance gradually increased with the pulse interval decreased. The illustration shows the comparison of the last pulse conductance under different time intervals. Then, the device achieves the behavior of PPF $\rightarrow$ PPD in Fig. 3(g) by changing the pulse interval. When the pulse interval was 6 μs , and 40 pulses were continuously applied, the response current increased in the negative direction. After the pulse interval changed to 14 μs and the pulses number was 10, the response current shows a reversed increase. Thus, the neural-synapses-like behaviors [35] of PPF and PPD were simulated. Long-term plasticity is equally important in the simulation of neural synapses, which includes two functions: LTP and LTD [36]. As shown in Fig. 3(h), the yellow part on the left indicates that 30 pulses with an amplitude of -4 V, the pulse width and interval of 3 μs were applied to the device, and it was found that the conductance gradually increased. The blue part on the right represents that 30 pulses with opposite amplitudes but the same pulse width and interval were applied to the device to simulate the LTD. It shows that the device successfully achieved bidirectional conductance regulation. This pulse regulation characteristic further provided an important foundation for the research on the biomimetic behavior of nerve synapses. This demonstrates its significant advantages in neural network computation.

Because this hetero-memristor possesses superior photoresponse characteristics, to verify its response to different optical wavelengths, the changes in the response current were further demonstrated in Fig. 4(a) under three different power density (0.64, 1.59, and 2.23 W/cm^2) for 520 and 405 nm at -1 V bias, respectively. The device shows the stronger response at 405 nm and with the power increases, the response current gradually increases.

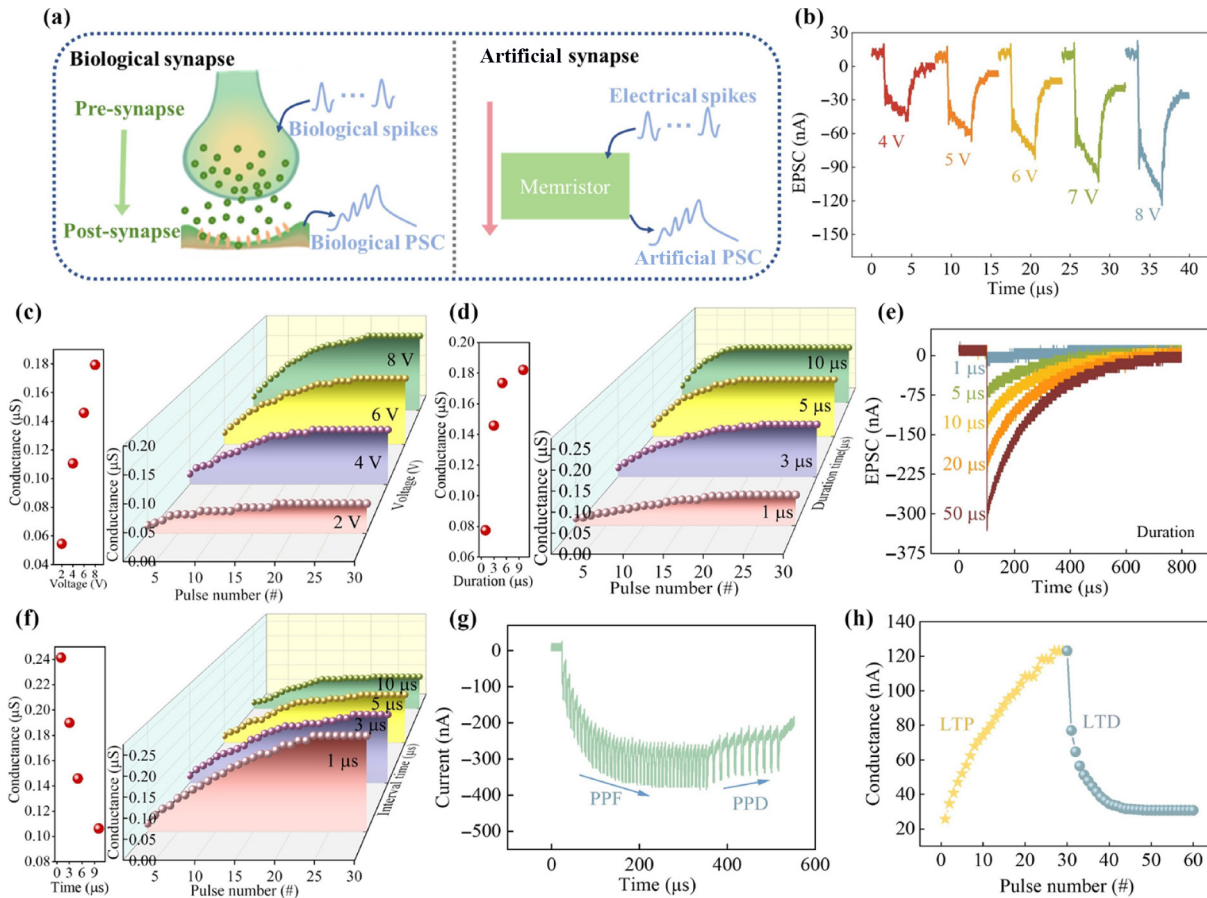


Figure 3 Electrical conductance regulation for biological synapses simulation. (a) Illustrating diagram of the analogy between biological synapses and artificial synapses. (b) EPSC variation under different pulse amplitudes (-4, -5, -6, -7, -8 V). (c) Conductance modulation after applying 30 pulses at different amplitudes continuously (-2, -4, -6, -8 V). (d) Conductance modulation after applied 30 different pulse-width pulses consecutively (pulse-width: 1, 3, 5, 10 μ s). (e) Comparison of EPSC after applying different pulse widths (1, 5, 10, 20, 50 μ s). (f) Conductance modulation after applied 30 different pulse-interval pulses consecutively (pulse interval: 1, 3, 5, 10 μ s). (g) Behavior simulation from PPF to PPD. (h) LTP and LTD modulate synaptic weights.

For confirming the long-term usage conditions, ON/OFF switching light pulses were repeatedly applied to assess the stability of the device, it is finally found that the device can operate for over 30,000 cycles without obvious attenuation, as shown in Fig. 4(b). Based on this, the optical logic AND gates are designed by LT spice, the circuit is shown in Fig. 4(d), two memristors are connected in parallel, terminals A and B are the input terminals and terminal Y is the output terminal, once we get the optical signal, transmit the signal to the transimpedance amplifier (TIA) to process and amplify it. The parameters of specifically setting in LT spice are as follows: The 405 nm light applied to the device under -1 V bias, the optical RESET current is -51 μ A as the input high current, and the optical SET current is -52 μ A as the input low current. Three level signals were obtained, which were 132.25, 131.00, and 131.70 mV, respectively. After that, the signal is input to the comparator, and the logic AND, OR circuit is realized by adjusting the threshold voltage (V_{th}), respectively. When V_{th-} is set to 131.84 mV, the circuit realizes the AND gate function, as the V_{th+} is set to 132.11 mV, the circuit realizes the OR gate function, as shown in Fig. 4(c). Specifically, when the voltage at the inverting input (-) is higher than the voltage at the positive input (+), the output is a negative saturation voltage (0 V). Conversely, when the voltage at the inverting input is lower than that at the positive input, the output is a positive saturation voltage (5 V). Finally, the obtained high level (logic 1) is 5 V and low level (logic 0) is 0 V. To confirm the

feasibility of using actual devices for optical logic operations, a breadboard circuit was used to experimentally validate the LT spice simulation results. The basic optical AND gate used two real memristive devices, as shown in Fig. S9 in the ESM. The two yellow wires are connected to two actual memristors respectively, connecting the two devices in parallel. Then, corresponding optical pulses are applied to them, and the photocurrent responses were shown in Fig. S10 in the ESM as input current. When light is applied to both devices simultaneously, the circuit output V_{OUT} is 5 V (logic "1"), and the others are 0 V (logic "0"). Figure S10 in the ESM shows the logic output of the corresponding output terminal.

Based on this, we further integrate two CMOS to design XOR and XNOR logic gates based on OR and AND logic circuit. Firstly, an inverter is built by using two CMOS, the output terminal of the OR logic gate is connected to the inverter power supply terminal (VCC), and the output terminal of the AND logic gate is connected to the input terminal of the inverter. By this way, the output signal of the inverter is the output signal of the XOR logic circuit. And the simulation results are shown in Fig. 4(e). When the two input currents are different, the output is 4.5 V, and in other cases it is 0 V. If the output of the OR logic circuit is used as the input of the inverter, the output of the AND logic circuit is connected to the GND end of the inverter, and the VCC voltage of the inverter is set to 5 V, the XNOR logic circuit can be realized. The simulation results are also shown in Fig. 4(f). During the transmission of

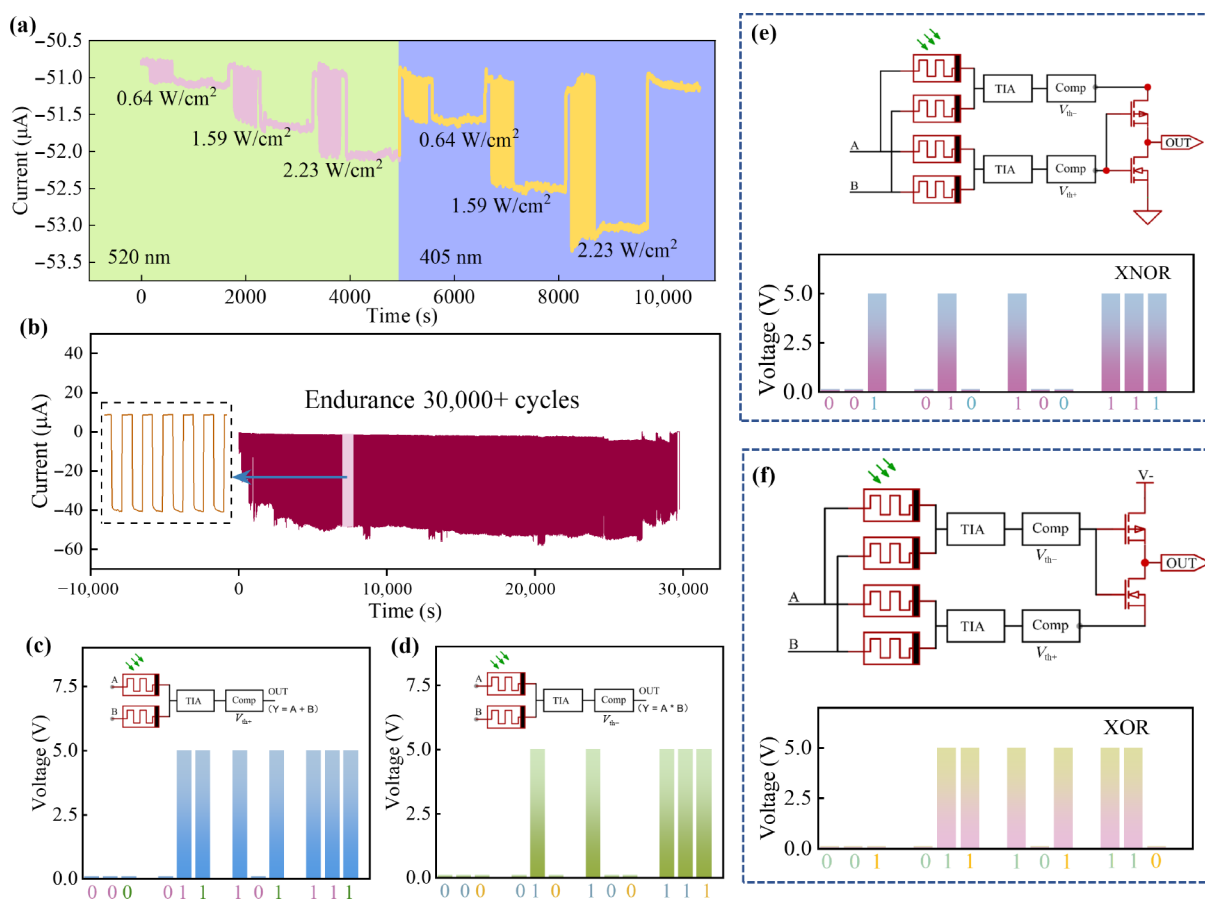


Figure 4 Robust optical properties and the construction of optical logic gates. (a) Current response under different wavelengths at different optical power density. (b) 30,000+ cycles endurance of optical switching. (c) Construction of optical logic OR gates and simulation results. (d) Construction of optical logic AND gates and simulation results. (e) Construction of optical logic XNOR gates and simulation results. (f) Construction of optical logic XOR gates and simulation results.

binary information, errors may occur due to noise interference. The ODD checker verifies whether an error has occurred during transmission by detecting the parity of the number of “1” in a set of binary codes [37]. Using the basic logic gate circuit constructed previously, a four-bit ODD checker is further constructed to verify the parity of the photocurrent input. The combined circuit diagram based on three XOR gates is shown in the Fig. 5(a), where A, B, C, D are the input terminals and Y is the output terminal. When there is an odd-number input currents of $-51 \mu\text{A}$ among the four input terminals, the output terminal Y will output a high level of 4 V (logic 1), while the number of $-51 \mu\text{A}$ input currents among the four input terminals is even, the output terminal Y will remain at a low level of 0 V (logic 0). The simulation results conducted on the input of “0000” to “0111” are shown in Fig. 5(b). By comparing the simulation results with the true value table of ODD, it can be found that the logical results are completely consistent, indicating that the ODD checker constructed by hetero-memristors can successfully perform ODD checking, all the simulation results are shown in Figs. S11–S15 in the ESM.

In the era of information technology, the acquisition of information no longer solely relies on traditional electrical transmission. Instead, it is trending towards low-power and high-efficiency optical signals. Thus, the security issue of optical transmission urgently needs to be addressed. Due to its stable and durable performance, as well as the implementation of the five logic gates we constructed, this device possesses the capability to build an optical encrypted communication system. Furthermore, based on

its adjustable conductance, the device’s in-memory computing capability allows for further physical encryption after obtaining basic photocurrent encoding. Additionally, the neural network with LTP/LTD conductance modulation obtained by this device can simulate recognition of various datasets. In Fig. 5(c), it shows the optical communication system based on those basic logic operations [38]. Once the device perceives the message, it can split the image into pixels. Then, certain logical operations are performed between each row of segmented image pixels and the key, thereby enabling encrypted image transmission. We adopt the MNIST database containing 28×28 -pixel images and use the light detection function to complete the light response encoding of the binary MNIST. The original grayscale images are converted into binary images, pixels with grayscale values exceeding 127 are designated as “1” (indicating photosensitive regions), while the remaining pixels are assigned “0” (denoting non-responsive areas). Figure 5(c) shows that each column of 28 pixels is converted into a sequence of spiking pulses, with a total of 28 pulses emitting optical signals sequentially to achieve imaging processing. This process is demonstrated through an example displaying the digit “8”. Through logic gates, XOR or XNOR operations can be performed to achieve encrypted encoding, the encryption results were shown in Fig. 5(d). This encoded signal is then integrated and input into the computer for encrypted communication.

The handwritten digit recognition process was constructed to initially synaptic functionality of the devices, using optical response encoding as the neural network input layer. The encoded image is

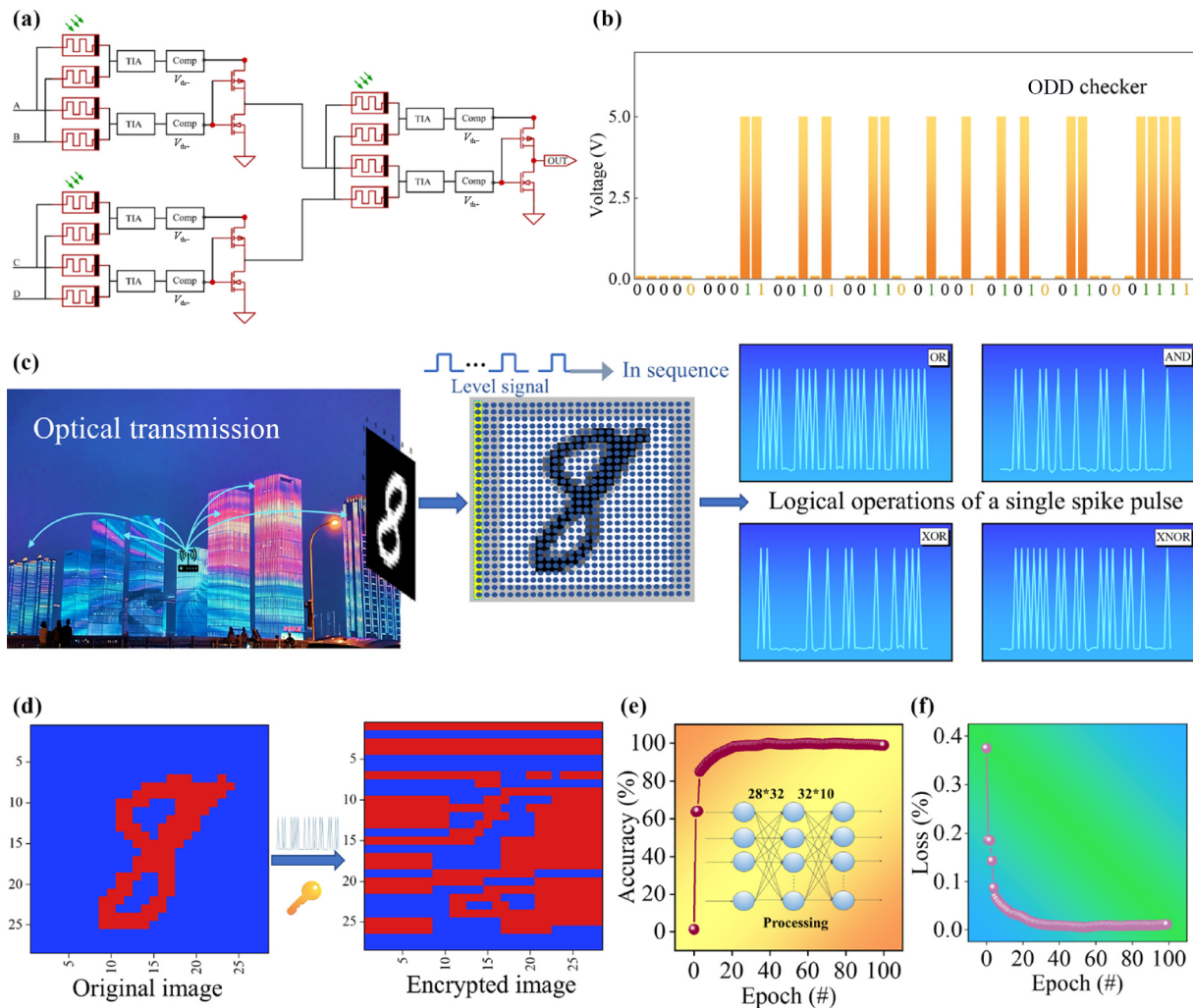


Figure 5 Realization of space optical encryption communication system. (a) ODD checker circuit constructed by optical logic XOR gate. (b) Simulation results of the ODD checker circuit. (c) Process diagram of optical communication encryption. (d) The image after encryption. (e) Accuracy of digital handwriting recognition over 100 iteration cycles. (f) Loss of the recognition over 100 iteration cycles.

converted into a pulse stream, which is fed into the memristor-based neural network at varying speeds. Recognition results are then obtained using a trained readout function. Figure 3(g) shows the LTP and LTD conductance curves measured for preliminary simulation of synaptic functionality. These conductance changes are mapped to connection weights in the neural network, enabling device-level recognition simulation.

In the network architecture, the first layer is a fully connected layer, the input size is 28, the setting contains 28 neurons, and the activation function is ReLU

$$\text{ReLU}(x) = \max(0, x) \quad (1)$$

The second layer is also fully connected and contains 32 neurons with the same activation function as the first layer. The output layer has 10 neurons corresponding to 10-digit categories, and the activation function is softmax

$$\text{softmax} = \frac{e^{Z_i}}{\sum_{j=1}^C e^{Z_j}} \quad (2)$$

where Z_i denotes the raw output, and C represents the total number of categories, yielding the probability of each category among all

classes. After multiple rounds of training, the network achieved 99.8% accuracy in the handwritten digit recognition task as shown in Figs. 5(e) and 5(f), demonstrating the device's superior synaptic computing capabilities and the feasibility of spatially encrypted optical communication.

3 Conclusion

In summary, a $\text{ReSe}_2/\text{BST:YSZ}$ hetero-memristor was fabricated to achieve ferroelectric modulation and broadband optical perception. Due to the regulation of the interface barrier between ReSe_2 and BST:YSZ , the hetero-memristor finally achieves the wider band perception and a large photoresponse current of 50 μA and excellent optical-switching endurance exceeding 30,000 cycles. The device maintains stable I - V behavior and exhibits high-pressure (applied voltage 4–20 V) ferroelectric property, when the voltage reaches 20 V, $\text{Pr} = 12.3 \mu\text{C}/\text{cm}^2$. In addition, electrical pulses were applied to emulate synaptic behavior, including conductance modulation. The device responses under 4–8 V pulses, the EPSC under different pulse widths and intervals, as well as the PPF $\rightarrow$ PPD behavior and LTP $\rightarrow$ LTD switching were systematically investigated. The photocurrent under 405 nm illumination was

converted into a photovoltage to successfully realize optical logic operations, including AND, OR, XNOR, XOR, and ODD checker functions. Based on the space optical encryption communication system, the airborne information encryption transmission and the final 99.8% recognition rate accomplished. Therefore, the optical behavior of the hetero-memristor might lay the foundation for optical image-recognition and subsequent optical communication integrated.

Electronic Supplementary Material: Supplementary material (the basic TEM, XPS and XRD characterizations of the ReSe₂ film, 10⁷-cycle durability of ferroelectricity, comparison of light response with and without ReSe₂, mechanisms analysis of memristive and light response characteristics, and the implementation results of logic circuits) is available in the online version of this article at <https://doi.org/10.26599/NR.2026.94908594>.

Data availability

All data needed to support the conclusions in the paper are presented in the manuscript and the Electronic Supplementary Material. Additional data related to this paper may be requested from the corresponding author upon request.

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Declaration of competing interest

All the contributing authors report no conflict of interests in this work.

Author contribution statement

R. Y. L., W. D. S., and J. H. C. contributed to data curation, validation, manuscript writing and experimental design. J. Z., K. B. Z., Z. L. J., and H. N. L. contributed to data curation. J. W. Z., P. L., and H. W. contributed to the data interpretation and provided financial support.

Use of AI statement

None.

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